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INTENSE PULSED ION BEAM NEUTRALIZATION, FOCUSING,
AND COLLECTIVE PLASMA INTERACTIONS

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A Thesis

Presented to the Faculty of the Graduate School
of Cornell University
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy



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CHAPTER 1 INTRODUCTION

Intense pulsed ion beams have received attention in recent years as a candidate for driving inertial confinement fusion targets and heating magnetically confined plasmas⁽¹⁾. For these applications, the beam may be required to propagate in a vacuum or a background plasma under the influence of electric and magnetic fields. The purpose of this thesis is to study the propagation of an intense pulsed ion beam in ^{vacuum} ~~some of these~~ environments.

~~In this thesis,~~ three areas of ion beam propagation are studied: charge and current neutralization by electrons when a beam is injected into a vacuum region; focusing of a beam when it is axially injected into a solenoidal magnetic lens; and collective interactions when a beam passes through a background hydrogen plasma. The experimentally observed beam behavior in each of these situations is analyzed and compared with theoretical models. 59

In the experiment, a beam (360 keV., 65 amps/cm², 150 ns.) was extracted from a planar, magnetically insulated diode and injected into a field free vacuum region. The beam was found to be both charge and current neutralized by electrons drawn axially into the beam from the cathode of the diode. The neutralization process was modeled with a theory developed by Humphries⁽²⁾,⁽³⁾ which predicts the velocity distribution of the comoving neutralizing electrons. 60

To test Humphries' theory, a diagnostic technique using a biased charge collector was employed to make a direct measurement of the velocity distribution of the neutralizing electrons. A theory, described in this thesis, was developed to calculate the I-V curve for a biased charge collector. The theoretical curve was found to be a function of the neutralizing electron velocity distribution. By fitting a theoretical curve to the experimental data, the electron velocity distribution was found at various downstream locations from the diode.

Previous biased charge collector theories⁽⁴⁾ assumed the neutralizing electrons were cold, moving with the same velocity as the ions, and the charge collector bias voltage was large enough to stop all the neutralizing electrons. The theory described in this thesis treats arbitrary electron velocity distributions and bias voltages. The potential inside the charge collector was also calculated and used to explain why secondary electrons from the collector plate are not a major problem in biased charge collector operation.

An indirect measurement of the electron velocity distribution was made by measuring the beam floating potential. This was accomplished by building the capacitive probe described in this thesis. A surface in the beam channel was connected to ground through two capacitors connected in series. Due to the difference in potential between the beam and ground, the capacitors charged and the

surface rose to the floating potential. The capacitors formed a capacitive voltage divider and by measuring the voltage across the capacitor to ground the floating potential was found.

To simulate the conditions at the diode, a transverse magnetic field was placed across the beam channel to remove the neutralizing electrons. Just downstream from the magnetic field, a transverse screen was used as a dense source of secondary electrons which reneutralized the beam. The capacitive probe was used to measure the floating potential of the beam at various distances downstream from the screen. The observed behavior is presented in this thesis and compared with Humphries' theoretical model.

Collective focusing (ions and electrons have a common focal point) was studied by injecting the beam axially into a 0-5 kilogauss solenoidal magnetic lens. Previous work by Robertson^{(5), (6)} involved an experimental and theoretical investigation of collective focusing of an intense pulsed ion beam by a short (length \ll radius) solenoidal lens where the focal point occurred outside of the lens. In this thesis, collective focusing was studied with a long (length \gg radius) solenoidal lens where the focal point occurred inside the solenoid.

Collective focusing was experimentally observed by measuring ion current density at various axial and radial positions inside the solenoid. In a vacuum, a well defined focal point was found and the focal length as a function of

the applied magnetic field was measured. With a background plasma in the lens, the focus strength was found to decrease as the plasma density was increased and no focusing was observed when the plasma density was equal to or greater than the beam density. The experimental results are presented in this thesis and compared with a theoretical collective focusing model and numerical calculations.

Collective two stream instabilities were studied by passing an intense pulsed ion beam through a hydrogen plasma. The plasma was formed by a conical theta pinch gun and ejected into the path of the beam. As an indication of two stream instabilities, microwave emission was studied for plasma densities of 10-100 times the beam density. It was found that neither the beam ions or neutralizing electrons were able to drive a detectable two stream instability with the plasma electrons. The inability of the beam to drive a two stream instability is explained with the instability analysis developed in this thesis. Fast plasma electrons, accelerated by the beam, were found to drive a two stream instability and a detailed study of the microwave emission is presented in this thesis.

This thesis is arranged in chapter form with the experimental apparatus discussed in Chapter 2, ion beam neutralization in Chapter 3, collective focusing in Chapter 4, beam-plasma instabilities in Chapter 5, and Chapter 6 contains a summary of the results.